ICES WGINOR REPORT 2017

STEERING GROUP ON INTEGRATED ECOSYSTEM ASSESSMENTS

ICES CM 2018/SSGIEA:10

REF ACOM AND SCICOM

Interim Report of the Working Group on Integrated Ecosystem Assessments for the Norwegian Sea (WGINOR)

27 November - 1 December 2017

Tórshavn, Faroe Islands

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2018. Interim Report of the Working Group on Integrated Ecosystem Assessments for the Norwegian Sea (WGINOR). ICES WGINOR REPORT 2017 27 November - 1 December 2017. Tórshavn, Faroe Islands. ICES CM 2018/SSGIEA:10. 38 pp.
https://doi.org/10.17895/ices.pub.8613

Contents

Executive Summary

The Working Group on Integrated Ecosystem Assessments for the Norwegian Sea (WGINOR) was held in Tórshavn, Faroe Islands, on 27 November – 1 December 2017 and was chaired by Per Arneberg (Norway) and Guðmundur J. Óskarsson (Iceland). The number of participants were 22, representing Norway (5+10 on correspondence), Iceland (2), and the Faroes (5).

Progress on ToR A included updated assessment of the main components of the ecosystem, methodological development of integrated trend analyses and establishment of a basis for future development of IEA.

Modelling work for ToR B, based on ENAC and Atlantis, was discussed. Harvest control rules (HCR) were addressed with respect to effect of species interactions or climate variability. Potential ENAC model runs were planned. Atlantis work includes evaluation on multispecies HCR and is still in progress.

WGINOR will hold a meeting on the dynamics of the Norwegian Sea ecosystem in conjunction with the EcoNorSe project in Bergen, on 16-19 October 2018.

The science highlights addressed were the following:

Heat content in the Atlantic Water of the Norwegian Sea continued to increase and reached record high levels in 2017. This anomalous heat content is mainly confined to the Lofoten Basin. Freshwater content has increased slightly and water in the southern entrance to the Norwegian Sea cooled slightly. The Subpolar gyre has been strengthened during the last three years and may reverse the trend of decreasing amount of silicate entering the Norwegian Sea. Flow of Arctic water entering the southern Norwegian Sea is weak and leads to low biomass of zooplankton there.

From high levels during the early 2000s, the zooplankton biomass index declined until 2010, which coincided with increasing biomass of pelagic fish stocks. Since then the index has increased and is currently around the long-term mean.

Stock size and summer feeding area of mackerel *Scomber scombrus* has increased the last decade. Northwards expansion of spawning has been observed with increased occurrence of 0-group in Nordic Seas. Several strong year classes have entered the adult stock, with the 2014 year class being the last one. Feeding intensity in the Norwegian Sea and adjacent waters is likely to remain high.

Norwegian spring-spawning herring *Clupea harengus* has not produced a strong year class after the productive period of 1998–2004, causing declining stock size since 2009. More westerly feeding distribution in recent years has reduced spatial overlap with the increased density of mackerel, and the herring stock has maintained high individual growth rate and condition.

Blue whiting *Micromesistius poutassou* biomass reached a maximum level in mid-2000s, declined thereafter to around 2010, but has since increased with income of strong year classes, the last one from 2014. This increases the feeding pressure.

Atlantic bluefin tuna has since around 2013 returned to Norwegian waters and may increase predation of pelagic fish.

A simulation study revealed that Principal Component Analyses on time-series may primarily reflect methodological artefacts. Alternative methods are proposed to sum-

marize adequately interannual variability patterns and test hypotheses about the functioning of the ecosystem. This includes Dynamic Factor Analysis and Structural Equation Modelling.

1 Administrative details

Working Group name

Working Group of Integrated Assessment of the Norwegian Sea (WGINOR)

Year of Appointment within the current cycle

2017

Reporting year within the current cycle (1, 2 or 3)

2

Chairs

Guðmundur J. Óskarsson, Iceland

Per Arneberg, Norway

Meeting venue

Torshavn, Faroe Islands

Meeting dates

27 November – 1 December 2017

2 Terms of Reference a) – c)

ToR descriptors for 2016–2019:

ToR	Description
A	Perform up to date integrated assessment for the Norwegian Sea ecosystem focusing on fisheries, but also considering other human pressures.
B	Utilize multispecies and ecosystem models to investigate effects of single and multispecies harvest control rules on fishing yield and ecosystem state for the purpose of developing ecosystem based advice.
C	Update the Ecosystem Overview for the Norwegian Sea.

3 Summary of Work plan

Year 1	Focus on understanding expectations of IEA end-users, continue the compilation of relevant time-series, and continue the work on integrated assessment for the Norwegian Sea
Year 2	Focus on, through modelling, single vs. multispecies harvest control rules for development on ecosystem based advice, and outstanding issues for integrated assessment
Year 3	Focus on advancing IEA in management advice, revise the time-series, perform integrated assessment, and update the Ecosystem Overview.

4 List of Outcomes and Achievements of the Working Group in this delivery period

- The dataseries compiled within WGINOR of the different environmental, ecological, and biological variables were updated.
- Revision of the section “Ecosystem considerations” within the 2018 Working Group on Widely Distributed Stocks (WGWIDE) report was initiated. This was done to make use of the experts in the different fields within WGINOR, which are not attending WGWIDE.
- Development of modelling work in Atlantis to examine multispecies harvest control rules for the Norwegian Sea continued and the process will be reported in a research paper and next year's WGINOR report.
- The group discussed how the work with integrated ecosystem assessment (IEA) in WGINOR should be developed in the years to come. This has included identification of (a) the parts of the ecosystem (including the physical environment) that can be included in the IEA work (b) the human drivers that can be included and (c) the types of activities that could be included in the further work with IEA in WGINOR (e.g. integrated trend analyses, risk assessment, management strategy evaluation etc.). In the year to come, this will be used to identify areas that should be prioritized in the further development of IEA in WGINOR.
- Presentation and discussions on the various research survey results (e.g. IESNS and IESSNS[1]), recent research papers, research projects (see Annex 2) were made. They are fundamental for advancing the future work of WGINOR as represented by its ToRs.
- The use of the PCA on time-series, as previously done by the Working Group, was challenged and other potential statistical tools identified (Dynamic Factor Analysis, DFA, and Structural Equation Modelling, SEM). Recruitment variation of NSS-herring will be used as a case study to validate the application of these methods for this purpose.
- Data on zooplankton dry weight from IESNS have been missing in the NAPES database for the years 1995–2007. The estimates in the WGINOR reports for that period have been based on data of low quality and insufficient information about the samples. Consequently, uploading of quality checked data with all relevant information attached was initiated during this year’s WGINOR meeting and will hopefully be completed early in 2018.
- A decision was made to arrange a meeting in Bergen on 15–19 October 2018 on “Dynamics of the Norwegian Sea pelagic ecosystem” (Annex 7). The meeting will be organized by WGINOR and the EcoNorSe project.

[1] IESNS: International Ecosystem Survey in the Nordic Seas
IESSNS: International Ecosystem Summer Survey in the Nordic Seas

5 Progress report on ToRs and workplan

Progress by ToR A: Perform up to date integrated assessment for the Norwegian Sea ecosystem focusing on fisheries, but also considering other human pressures.

- The state of the main components of the ecosystem has been assessed based on the updated dataseries;
- General basis for making inference about processes have been improved through studies that have been performed since last meeting and discussion at the meeting;
- Methodological development of integrated trend analyses has been done and avenues for future development identified;
- A basis has been established for discussing the future development of integrated ecosystem assessment in WGINOR.

Progress by ToR B: Utilize multispecies and ecosystem models to investigate effects of single and multispecies harvest control rules on fishing yield and ecosystem state for the purpose of developing ecosystem based advice.

A work towards ToR B presented and discussed during the WGINOR 2017 meeting relates mainly to three different models, ENAC, NORWEGOM and Atlantis. Several possible research questions to be dealt with by the models were identified and reported in the 2016 report (ICES 2017a). ENAC is a multispecies model for pelagic fish incorporating interaction and climate variability (ICES 2016a). The main objective of the model is to test harvest control rules following a standard management strategy evaluation (MSE) approach, where the effect of species interactions or climate variability can be explored. Some thoughts around this topic was addressed during the meeting (Annex 4). Potential model runs applying different scenarios were discussed and planned, which will be presented in next year's report.

Atlantis (Fulton *et al.*, 2011) is a modular modelling framework capable of producing realistic simulations of ecosystem dynamics. Atlantis serves as a strategic management tool capable of exploring ecological hypotheses, simulating climate scenarios, and testing human impacts on the environment including fisheries and the effect of wind farms. Atlantis integrates physical, chemical, ecological, and fisheries dynamics in a spatially-explicit, three-dimensional domain. A preliminary work on evaluation on multispecies harvest control rules for the Norwegian sea was introduced to the group (Annex 5). This work in progress will be better reported in a research paper and next year's WGINOR report.

It is expected that some results from the project Ecosystem Dynamic in the Norwegian Sea (http://econorse.imr.no/) will start to appear in 2018. NORWECOM will be applied there, among other things. This work is highly relevant to WGINOR and will be reported in the 2018 report as appropriate.

Some discussion was on how potential relevant findings by multivariate analyses and/or ecosystem modelling could be used in the fishery management of the pelagic fish stocks. This needs further discussion within the WG in future.

Progress by ToR C: Update the Ecosystem Overview for the Norwegian Sea.

A draft (not reported) of the ecosystem overview has been updated with more information on other human activities than fisheries. The revision will continue in the year to come.

Changes/Edits/Additions to ToR:

No changes were made to the ToRs and the workplan.

Cooperation with other WG:

Results from methodological development on multivariate analyses will be communicated to other regional IEA groups. The main message is that Principal Component Analyses are inappropriate to time-series and that other methods, such as Dynamic Factor Analysis (DFA) and Structural equation modelling (SEM) should be tried out.

Cooperation with Advisory structures:

The content of the section "ecosystem considerations" in the 2017 WGWIDE report (ICES 2017b) was mainly provided by the WGINOR group, which includes expertise in this field. In the same way, selected parts from the Science highlights (below) can be used in the 2018 WGWIDE report.

6 Science Highlights

There are numerous publications annually that at least partly address the Norwegian Sea ecosystem. However, there are a limited number of studies focusing on energy flow between or within trophic levels or overall ecosystem regulation. Further, there is a tendency for more focus on the commercial important species, or the three big pelagic fish stocks. Below is a summary of recent scientific results (published or submitted) presented at the meeting for the Norwegian Sea addressing large-scale features, trophic regulations and methodological development for integrated multivariate trend analyses.

Recent trends in oceanography and zooplankton

The time-series of ocean heat content in the Atlantic Water of the Norwegian Sea starting in 1951 show that the recent warm period continues (Figure 6.1). In fact, there is a continuing increase in 2017 compared to 2016 that was the previous record high value. This positive anomalous heat content is mainly confined to the Lofoten Basin. At the same time, the freshwater content shows a slight increase, i.e. freshening, which is not expected from the usual T-S relation of warm/saline and cold/fresh varying in concert. Such change could be either due to anomalous air-sea exchange or changes in the volume or characteristics of the source water masses.

In the southern entrance to the Norwegian Sea there is a tendency toward slightly colder water compared to the recent years. However, more remarked is a prominent freshening trend pointing toward increased influence of water from the western Atlantic.

The index of Arctic water into the southern Norwegian Sea with the East Icelandic Current appears still weak compared to the condition previous to about 2002. This is further reflected in low biomass of zooplankton in this region.

Upstream analysis of satellite sea surface height data indicates that the Subpolar gyre, which has been in a weak state for many years, has been strengthening during the last three years. If this trend continues, we should expect increased levels of silicate entering the Norwegian Sea over the coming years and consequently a reversal in the declining trend of silicate observed in the Norwegian Sea since 1990 (Rey, 2012; Pacariz *et al.,* 2016; Hátún *et al.,* 2017). The atmospheric forcing represented by the winter NAO-index was positive, for the third consecutive winter. In the Labrador-Irminger Sea this normally means higher windstress curl and larger ocean to air heat loss and thus enhanced Subpolar gyre. For the Norwegian Sea, however, the averaged windstress curl showed low values, indicating that the atmospheric lows did not follow their normal route through the Norwegian Sea.

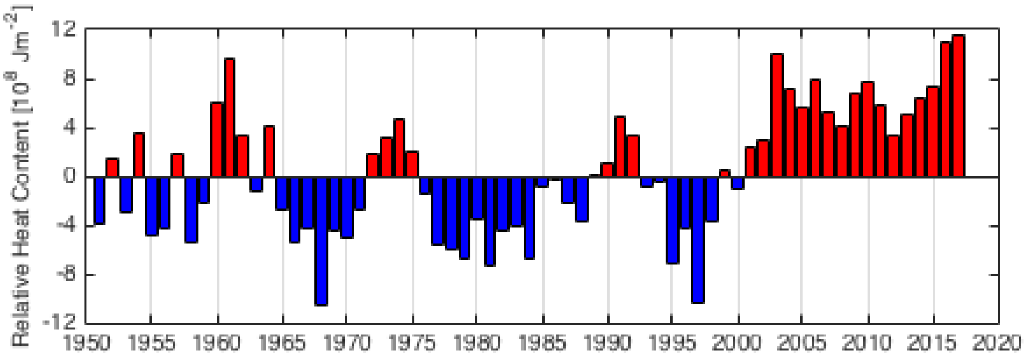

Figure 6.1. Time-series of anomalies of heat content of the Atlantic waters in Norwegian Sea (source: http://www.imr.no/temasider/klima/klimastatus/norskehavet/norskehavet_2/nb-no).

The time-series of meso-zooplankton biomass in the Norwegian Sea from the International Ecosystem Survey in Norwegian Sea (IESNS) in May shows strong long-term variability (Figure 6.2). Following a maximum in biomass during the early 2000s the biomass declined with a minimum in 2006. From 2010, the trend turned to an increase and reached the long-term mean in 2014. Biomass dropped again in 2015, but have been increasing since then. Interestingly, all the areas, excluding east of Iceland and on few occasions Jan Mayen AF (Figure 6.2), show parallel changes in zooplankton biomass.

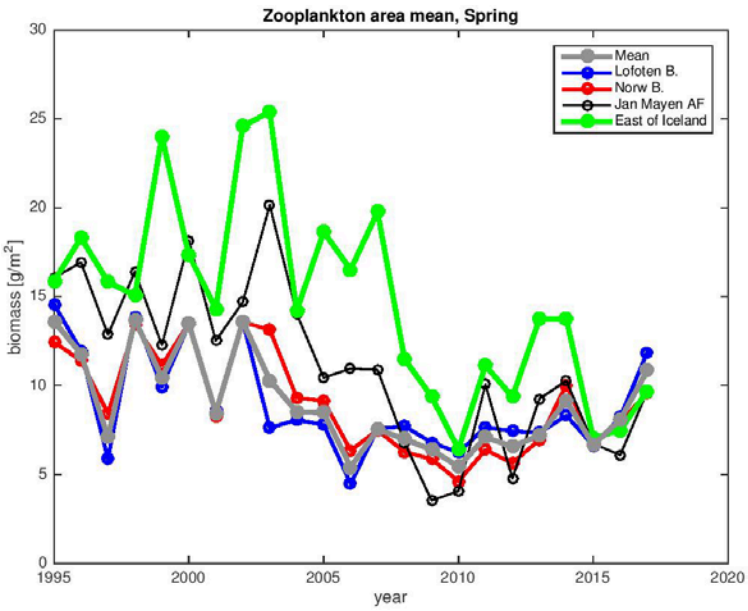

Figure 6.2. Indices of zooplankton dry weight (g m^{-2}) sampled by WP2 in May in different areas in and near Norwegian Sea from 1995 to 2017 as derived from interpolation using objective analysis utilizing a Gaussian correlation function (see details on methods and areas in ICES 2016a).

Decreased influx of *Calanus hyperboreus* and *Calanus finmarchicus* into the south-western Norwegian Sea

North of the Faroe Islands, hydrography and zooplankton have been monitored in May since 1993 along the so-called section N, which extends through Atlantic water, crosses the Iceland-Faroe Front (IFF), and into the Subarctic waters within the south-western Norwegian Sea (Figure 6.3a). Within the Subarctic region, a sudden reduction of large *C. finmarchicus* occurred in 2003, which has persisted (Kristiansen *et al.*, 2015). Simultaneously, *C. hyperboreus*, an expatriate from the East Icelandic Water (EIW), has largely disappeared. It has previously been assumed that the majority of *C. finmarchicus* is advected to section N from the Norwegian Basin. However, as the persistent changes of the *Calanus* spp coincide, this suggests that a portion of the overwintering *C. finmarchicus* population is advected with the EIW, together with *C. hyperboreus*. Therefore, these can be used as indicator species of a biogeographic shift based on shifting of the water mass boundaries. Around 2003, the zooplankton biomass, collected during the herring survey in May, showed a clear reduction within the EIW (Figure 6.4b), which indicates that section N is heavily influenced of zooplankton changes further upstream. Similar to section N, the zooplankton biomass there has remained low since.

Salinity and temperature characteristics show a variable eastward extension of the EIW tongue towards section N (Kristiansen *et al.*, in progress). In the early 2000s, the leakage from the EIW tongue, also known as the Modified East Icelandic Water (MEIW) (Figure 6.3b), spread far into the southwestern Norwegian Sea. In 2003, the eastward extension did not cross section N. This 2003 event coincided with atmospheric changes from an anticlockwise to clockwise wind pattern, which also caused the Norwegian Sea gyre to weaken its cyclonic pattern (Serra *et al.*, 2010). Collectively, it is likely that these forces have limited the eastward extension of the MEIW and thereby also contributed to the biological changes observed at section N (Figure 6.5). After 2003 the influx of the MEIW at section N has varied on a lower level compared to the years prior 2003, which shows good correspondence to the biological time-series at section N.

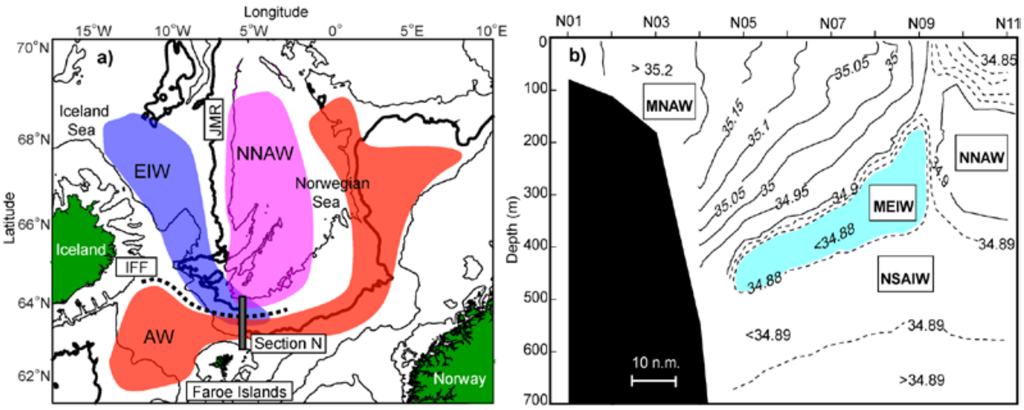

Figure 6.3. Map of study area. Water mass distribution within the upper layers that influence section N (thick grey line) (a) and average salinity distribution along the sampling sites at section N (N01-N11) with the main water masses indicated (b) (adopted from Hansen *et al.* (2003)). Abbreviations: AW, Atlantic Water; EIW, East Icelandic Water; NNAW, Norwegian North Atlantic Water; MEIW, Modified East Icelandic Water; MNAW, Modified North Atlantic Water; NSAIW, Norwegian Sea Arctic Intermediate Water; IFF, Iceland-Faroe Front; JMR, Jan Mayen Ridge. The 200, 500, 2000 (bold), and 3000 m isobaths are shown in (a).

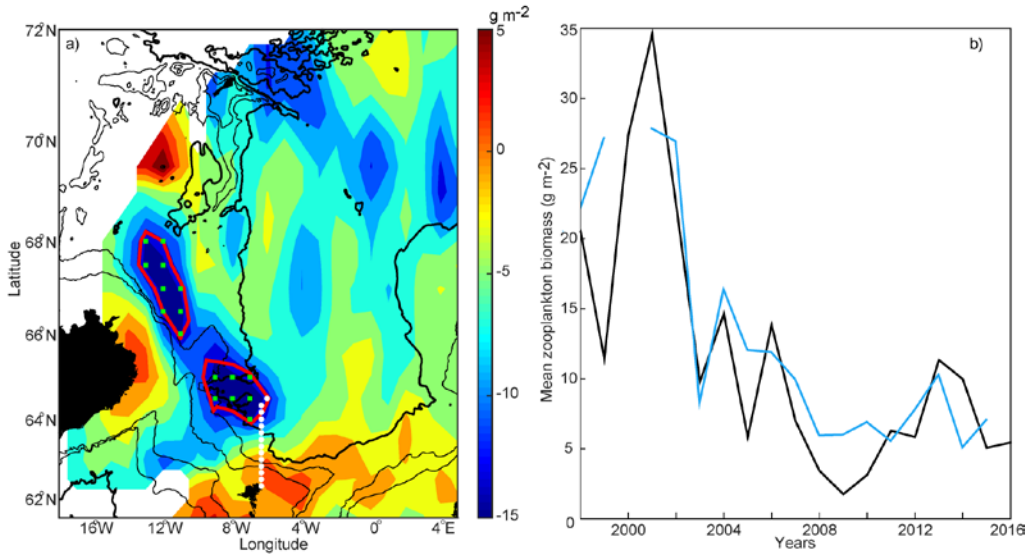

Figure 6.4. Difference in zooplankton biomass before (1998–2002) vs. after (2004–2016) 2003 (a). Section N (white dots) and the 500, 1000 and 2000 (bold) m isobaths are shown. Time-series of the mean zooplankton biomass from 1998 to 2016 is displayed in (b) for the two selected regions shown in (a). The blue and black line in (b) represent the upstream and downstream region, respectively. The time-series for the upstream region is shown with a one-year time-lag.

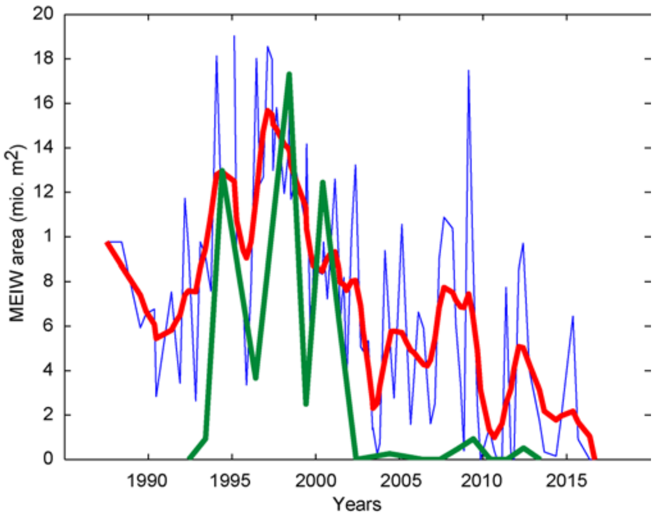

Figure 6.5. The abundance of *C. hyperboreus* (green) and the cross sectional area of Modified East Icelandic Water (MEIW) at section N. The MEIW area from individual occupations of this section are shown in blue while the red line shows the low-pass filtered (width of four data points) trend.

Atlantic bluefin tuna feeding in the Norwegian Sea

Norway was one of the largest and dominating fishing nations targeting Atlantic bluefin tuna (*Thynnus thunnus*) in the Northeast Atlantic Ocean during the 1950s and 1960s, with purse-seine catches reaching 15 000 metric tonnes inside the Norwegian Exclusive Economic Zone (EEZ) (Hamre and Thiews, 1964; Nøttestad and Graham, 2004; 2005; ICCAT 2016). The first fish appeared in early July, starting with the arrival of the largest fish, and extended through to October (Nøttestad and Graham, 2004). The Norwegian fishery ceased in the early 1980s as the abundance of bluefin tuna was severely reduced. Bluefin tuna was occasionally observed in Norwegian waters during the 1980s and 1990s, but not in quantities that could sustain a commercial fishery. Atlantic bluefin tuna has since around 2013 returned to Norwegian waters, and are re-establishing their traditional annual feeding migration pattern (Annex 6). There have been numerous observations and catches of bluefin tuna in 2016 and 2017 (Figure 6.6). Totally 235 individuals (~53 000 kg) were caught from targeted bluefin tuna fishing in 2017. The major driving force for the reappearance of bluefin tuna in Norwegian waters is probably increased need for prey, due to increased stock size over the last decade. Bluefin tuna are thus migrating further and further northeast into the productive Norwegian Sea ecosystems. Based on stomach samples from bluefin tuna caught in Norwegian waters in 2016 and 2017, the diet consisted predominantly of 0-group mackerel. Individuals had also to a lesser extent eaten larger mackerel, herring, blue whiting and gadoid species. Due to the high metabolism of bluefin tuna a large individual may possibly consume in the range of 1500 kg prey during one feeding season. Hence, with increasing abundance of bluefin tuna in the Norwegian Sea in the coming years, the total predation of pelagic fish by bluefin tuna may be substantial.

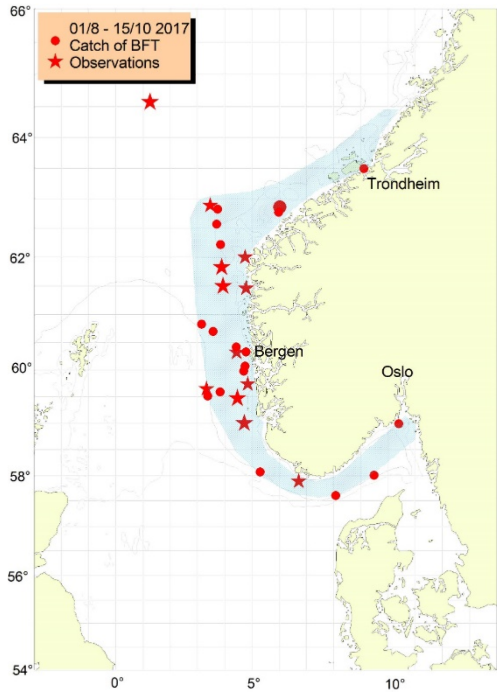

Figure 6.6. Geographical positions on catches and observations of bluefin tuna from August to October 2017.

Recent trends in stock dynamic of the pelagic fish stocks

The three dominating pelagic fish species in the Norwegian Sea are Norwegian Spring Spawning-herring (NSS-herring), mackerel, and blue whiting. The spawning-stock biomass (SSB) of blue whiting has increased since 2016 to an estimate of 6.2 million tonnes in 2017, while NSS-herring and mackerel SSB have declined and are in 2017 estimated to be 4.1 and 3.5 million tonnes, respectively (ICES 2017b; Figure 6.8). All species are currently harvested with a realized F above F_{MSY}, mainly due to disagreement between the coastal states on quota allocations. NSS-herring has not produced a strong year class since 2004, while both mackerel and blue whiting have produced several strong year classes in recent years (Figure 6.7). The occurrence of 0-group mackerel along the Norwegian coast evident in 2016, continued in 2017. The 1-year old mackerel were caught in coastal surveys along large parts of the Norwegian coast north to around 68-70 ºN. While the blue whiting stock currently is dominated by young individuals (age <5 year), mackerel is dominated by the 2014-year class (age 4–7 also abundant), and NSS-herring has relatively large number of old fish (age 12+) due to the number of poor year classes entering the stock since after 2004.

If the TAC advice will be followed for the stocks, the NSS-herring stock will remain at similar level in 2019 while the blue whiting stock and the mackerel stock are expected to decrease (ICES 2017b). The migration dynamics have not changed much the last years, except for a trend of NSS-herring overwintering further west in the Norwegian Sea instead of in northern Norwegian fjords. There are also strong indications of the mackerel spawning area now extending to the northern North Sea or southern Norwegian Sea, based on the abundant 0-group mackerel along the Norwegian coast.

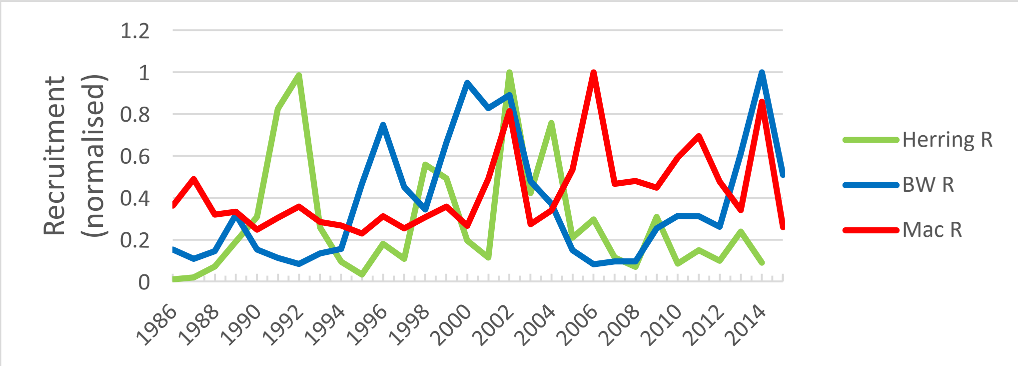

Figure 6.7. Year-class strength (i.e. recruitment, normalized) of Norwegian spring-spawning herring, blue whiting and mackerel over 1981-2017 based on the most recent assessments (ICES 2017b).

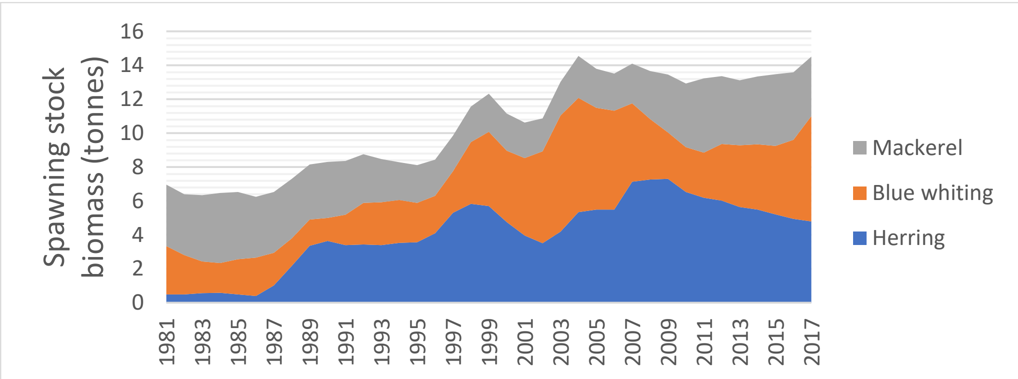

Figure 6.8. The cumulative spawning-stock biomass of Norwegian spring-spawning herring, blue whiting and mackerel from 1986 to 2017 according to the most recent assessments (ICES 2017b).

Methods for integrated trend analyses

Principal Component Analysis (PCA) is the most common multivariate analyses used for trend analysis in marine integrated ecosystem assessments (IEA), and the method has been used widely in ICES IEA groups to summarize the dynamics of marine ecosystems. During WGINOR 2016, a small data simulation study was conducted to evaluate the performance of PCA to reveal common temporal patterns and connections between ecosystem variables in the Norwegian Sea. The results suggested that, because the underlying datasets are time-series that are autocorrelated and/or non-stationary, most of the patterns revealed by the PCA could have emerged by chance. The study has been extended to other datasets from the Barents, Baltic and North Seas (Planque and Arneberg, 2017). The updated results show that most of the patterns revealed by the PCA can emerge by chance and that the fraction of the variance that cannot be accounted for by random processes is minimal. The Norwegian Sea dataset is a pathological case in which the variance explained by the first two components only exceeds what would be expected from randomly simulated time-series by 2%. The conclusion of this study is that outputs from PCA provide very little insight into the Norwegian Sea ecosystem status, trajectory and functioning.

Beyond PCA, the Norwegian Sea IEA needs to be equipped with methods that can provide better insight into how marine ecosystems function, the drivers of their changes and their possible future trajectories. Two methods were presented as possible candidates: Dynamic Factor Analysis (DFA) and Structural equation modelling (SEM).

DFA is a dimension-reduction technique especially designed for time-series data. It can be used to model short, non-stationary time-series for common patterns and explanatory variables. DFA is an alternative candidate to PCA as the technique is used to detect common patterns in a set of time-series and the relationships between these series and explanatory variables. The method has previously been applied to fisheries time-series (Zuur *et al.,* 2003). DFA model is a type of Multivariate AutoRegressive State-Space (MARSS) model in which observations are modelled as a linear combination of hidden trends and factor loadings, covariates, plus some offsets.

SEM is a modelling technique that explicitly considers causal relationships (Shipley, 2016). The method requires the formulation of an underlying structure of the system, which includes causes and effects. These relationships are then translated into mathematical equations, often linear models (although other models can be used). The resulting numerical model is evaluated against data in order to support or refute model structure and to eventually estimate model parameter values. By combining inferences across multiple equations, SEM addresses both direct (proximate) and indirect (ultimate) effects in a system. SEM is not originally designed for time-series, but the modelling framework can explicitly incorporate temporal autocorrelation or include autoregressive processes. While DFA may be favoured as a method to summarize multiple time-series, SEM is an inferential approach in which hypotheses about ecosystem functioning can be evaluated against empirical observations.

The use of both methods will be explored by WGINOR (with a clear preference for SEM). Dedicated simulation studies, analogous to the one performed on PCA, are envisaged to evaluate the performance of DFA and SEM in the WGINOR context. A meeting for trying out SEM for addressing hypotheses for recruitment in Norwegian spring-spawning herring is being proposed (see Annex 8).

7 Revisions to the work plan and justification

Not applicable.

8 Next meeting

Meeting in year 3: Reykjavik, Iceland, 26–30 November 2018

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Annex 1: List of participants

Name	Institution	E-mail
Eydna i Homrum	Faroese Marine Research Institute, Faroe Islands	eydnap@hav.fo
Jan Arge Jacobsen	Faroese Marine Research Institute, Faroe Islands	janarge@hav.fo
Sólvá Káradóttir Eliasen	Faroese Marine Research Institute, Faroe Islands	solvae@hav.fo
Inga Kristiansen	Faroese Marine Research Institute, Faroe Islands	ingak@hav.fo
Hjálmar Hátún	Faroese Marine Research Institute, Faroe Islands	hjalmarh@hav.fo
Gudmundur J. Oskarsson	Marine and Freshwater Research Institute, Iceland	gjos@hafro.is
Hildur Petursdottir	Marine and Freshwater Research Institute, Iceland	hildur@hafro.is
Per Arneberg	Institute of Marine Research, Norway	per.arneberg@imr.no
Hein Rune Skjoldal	Institute of Marine Research, Norway	hrs@imr.no
Kjell Utne	Institute of Marine Research, Norway	kjell.utne@imr.no
Øystein Skagseth	Institute of Marine Research, Norway	oistein.skagseth@imr.no
Benjamin Planque	Institute of Marine Research, Norway	benjamin.planque@imr.no
By correspondence:		
Elvar H. Hallfreðsson	Institute of Marine Research, Norway	elvar.hallfredsson@imr.no
Leif Nøttestad	Institute of Marine Research, Norway	leif.nottestad@imr.no
Nikos Nikolioudakis	Institute of Marine Research, Norway	nikolaos.nikolioudakis@imr.no
Cecilie Hansen	Institute of Marine Research, Norway	cecilie.hansen@imr.no
Cecilie Broms	Institute of Marine Research, Norway	cecilie.thorsen.broms@imr.no
Anne Kirstine Frie	Institute of Marine Research, Norway	anne.kristine@imr.no
Leif Nøttestad	Institute of Marine Research, Norway	leif.nottestad@imr.no
Erling Kåre Stenevik	Institute of Marine Research, Norway	erling.kaare.stenevik@imr.no
Morten D. Skogen	Institute of Marine Research, Norway	morten.skogen@imr.no
Svein-Håkon Lorentzen	Norwegian Institute for Nature Research – NINA, Norway	svein.lorentsen@nina.no

Annex 2: Agenda of the meeting

WGINOR 27 Nov.-1 Dec. 2017, Faroe Marine Research Institute, Tórshavn

Monday

10:00 Meeting opens, housekeeping, Introductions, planning (GJÓ and PA).

- Review of the TORs (GJÓ and PA).
- Content of the final report and tasks (GJÓ and PA).

11:30 Presentations

Mark Dickey-Collas: Perspectives on integrated ecosystem assessments within the ICES framework. (45 minutes talk and 45 minutes for discussion afterwards).

13:00 Lunch at the institute

14:00 Presentations continue –breaks in between as needed. 30 minutes including discussion for each presentation.

Inga Kristiansen: Marine climate, zooplankton and herring (precise title will come later)

Hildur Pétursdóttir: The linkage between environmental factors, zooplankton and herring in the Norwegian Sea

Øystein Skageseth: Oceanographic status for 2017

Eydna i Homrum: Key results from 2017 pelagic ecosystem cruises

Benjamin Planque: Multivariate statistics of time-series

17:00 Social event

Tuesday

09:00 Working session, breaking into groups:

- Models and ToRb
- Multivariate statistics of time-series and other aspects integrated trend analyses

12:30 Lunch at the institute

13:00 Working session continued with the same groups

17:00 End of working day

Wednesday

09:00 Plenary: Report on progress and discussion – modelling and integrated trend analyses.

11:00 Working session,

12:30 Lunch at the institute

13:00 Working session continued

17:00 End of working day

Thursday

09:00 Report status, working of the reports continued

12:30	Lunch at the institute
14:00	Plenary and discussions, outlining work to be done in the year to come
16:30	Group excursion?

Friday

09:00	Review of report, Working on reporting and any other business
12:15	Lunch at the institute
13:00	Plenary review and finalization of report
~14:00	Meeting closes (<u>even earlier, depending on flights etc</u>)

Annex 3: Recommendations

RECOMMENDATIONS	ADRESSED TO
1. In the last two decades, changes and expansions have been seen in feeding locations of the pelagic fish stocks in the Nordic Seas (e.g. NE-Atlantic mackerel, NSS-herring, Icelandic capelin). All information suggests that abundance of pelagic fish in Greenland Sea is currently small. However, climate changes might enhance these observed expansions of pelagic fish further and possibly into Greenland Sea. If and before such changes occur, it is important to record the "original" stage and record potential changes in the ecosystem and environmental variability. Consequently, WGINOR recommends that the International Ecosystem Summer Survey in Nordic Sea in July/August (IESSNS) will be extended into Greenland Sea. Whether this should be done every year or every second year can be discussed.	WGIPS

Status on recommendations from WGINOR 2016 to WGIPS

WGINOR 2016 made six recommendations to WGIPS regarding procedures and sampling on the ecosystem surveys in the Nordic Seas (IESNS and IESSNS). The answers to these recommendations are summarized below.

1. Nutrients are currently being sampled on the Icelandic and Norwegian vessels at IESNS, and the other countries are considering applying this procedure. On the IESSNS survey, this task is problematic on most cruises, as they are conducted by hired vessels, which do not have the necessary transmission cables for collecting water samples with the CTD.
2. WGIPS replied that time constraints prohibits CTD-measurements down to 1000 m on all stations on IESSNS. WGINOR 2017 noted that the casts down to 1000 m on the IESNS survey are in most cases sufficient to describe oceanographic features.
3. All vessels will aim for recording opportunistic sightings of marine mammals. A Norwegian protocol will be distributed.
4. Iceland and Norway use krill trawls on IESNS, and Faroes and EU will take the recommendations to the institutes for discussion. Regarding IESSNS, time constrains are prohibiting extensive krill trawling.
5. A subgroup will work intersessionally analysing krill trawl data to refine the request to a limited number of krill trawls.
6. The recommendation regarding weighing stomach of all fish that are sampled for age determination has been delivered to the relevant institutes participating in IESNS and IESSNS.
7. Guidelines regarding procedures in zooplankton sampling (WP2) on IESNS and IESSNS have been delivered to the participating parties and they will aim to follow them as thoroughly as possible

Recommendations to WGINOR 2017

ID36 - From WGIDEEPS

Recipients: NWWG, AFWG, WGINOR, Secretariat, SSGIEOM

Recommendation: 1. Advisory groups which use data from WGIDEEPS should make formal data requests to the group (submit a ToR to WGIDEEPS) to ensure that specific data products can be prepared and provided to advisory groups on time.

Final recipient action: The group noted that if data from WGIDEEPS are required, a formal request is made to WGIDEEPS.

ID129 - From WGMARS

Recipients: WGCOMEDA; WGEAWESS; WGIAB; WGIBAR; WGICA; WGINOR; WGINOSE; WGNARS

Recommendation: 2. Reply to WGMARS IEA survey questions before February 2018

Final recipient action: Status of recommendation is 'Rejected' and the group takes no further action.

Annex 4: Thoughts on multispecies MSE by Kjell Utne

Density-dependent growth is well documented, but this mainly occur within a stock. Ólafsdóttir's paper (and some analyses we did in the ENAC-project) further show that there are indications of competition between stocks. This affects the growth of mackerel and blue whiting, but not herring.

The idea is multispecies HCR can lead to less competition between stocks and therefore higher individual growth. Put differently, that a higher F on for instance herring will result in higher biomass of mackerel. The F_{MSY} for all these three species are determined by P(SSB < B_{lim}) < 0.05. Hence, increasing F will lead to a higher risk of SSB < B_{lim}, which would be very hard to support to get higher catches of another species. Thus, a multispecies HCR must ensure that P(SSB < B_{lim}) < 0.05 for all species, while still reducing interactions by avoiding SSBs being too high.

It is difficult (impossible?) to quantify the effect of interspecific competition, but for the following example let's say this accounts for 20% of the observed variation in weight-at-age for mackerel. To get a feel of the possible effect of adjusting F we can look at the effect of increasing F for herring. Let's assume that $B_{trigger}$ is fixed, and one go for F = 0.15 instead of F = 0.125. The would lead to a herring stock that is on average around ~15% smaller.

How would this for instance affect mackerel?

Assuming a linear relationship between stock size(s) and growth, and:

- 20% of the difference in growth for mackerel is due to interspecific competition
- A higher F for herring lead to 15% smaller herring stock

This would increase the weight-at-age for mackerel, by 3% (20%*15%) **of the variation in weight-at-age**. Assuming that the variation in weight for a 6-year old mackerel is in the range 400-600 g (roughly the maximum and minimum weight-at-age observed), this would mean that the fish would be 6 grammes, or around 1-1.5% heavier.

Model simulations are needed to quantify exactly how this affects the mackerel yield, but an estimate is that increased mackerel yield (due to a higher F on herring) would be < 10 000 tonnes. This would most likely not affect F_{MSY} for mackerel, but if so, it would increase F_{MSY} by 0.01.

To greatly increase the risk of herring SSB < B_{lim} (and increase interannual variation (IAV)) with the purpose of catching maximum 10 000 tonnes of mackerel more is not a realistic option. What about other HCRs that don't increase the risk of herring SSB < B_{lim}? One can for instance raise the $B_{trigger}$ and have a higher target F, or one can have 2 step HCR (like for NEA cod). Such rules can reduce the variation in SSB, but only to a minor extent. The average SSB will be about the same. The range of realistic F's is fairly limited due to the requirement of some sort of stability for TAC between years, and a higher F at high SSB's will naturally require lower F's at low SSB's.

An example from the last evaluation for mackerel (both HCR precautionary):

$B_{trigger}$ = 2.57 millions and F = 0.21 gives a median SSB = 3.63

$B_{trigger}$ = 5 millions and F = 0.28 gives a median SSB = 3.48

Similar results/patterns can be expected for the two other species.

Hence, adjusting the HCR for one species within reasonable ranges will only have a small effect on average SSB, and therefore not affect other species significantly. Further, HCRs with increased $B_{trigger}$ will result in higher IAV and or/lower long-term yield for the target species.

The discussion above assumes that there is a linear relationship between total biomass and individual growth. However, if individual growth is reduced only when the total biomass reaches a certain level, all results will be different. For instance, if the ecosystem can handle 15 million tonnes pelagic fish without loss in individual growth, but with rapid reduced growth at higher biomasses.

So my conclusion is:

1) How interspecific competition affects weight-at-age is hard to quantify, and statistical analyses have indicated the effect to be minor.
2) Even if the effect of interspecific competition on growth is quantified, the drawbacks with multispecies HCRs (high IAV, increased risk of SSB < B_{lim}, lower yield of the target species) are greater than the positive effects (increased yield of other species)

So why is not multispecies HCR for pelagic fish more beneficial:

1) The three species are all of high economic importance, so one cannot “sacrifice” one of the species. Blue whiting is the species with less economic yield, at least per kg, but this is also the species with less impact on the other species.
2) Present management apply an F where the limitation is the risk of SSB < B_{lim}. Hence, increasing F beyond present values for any of the stocks to reduce interactions would be a big problem.
3) Present management set stability as an important attribute. Hence, modified HCRs will give larger fluctuations to the managed stocks, and the negative interactions between stocks can only to a certain degree be “fixed” with altered HCRs.

Although multispecies HCRs don't seem to give a significantly improved management when looking at competition and reduced growth, this doesn’t mean that multispecies HCR never can be beneficial for these species/ecosystem. Possible issues that can be looked at are:

1) Intraquild predation – predation on fish larvae. Especially if total predation on larvae is not linear to predator SSB.
2) Fisheries targeting different trophic levels. For instance, a fishery for *calanus* vs. a fishery for pelagic fish.

Annex 5: Multispecies harvest control rules in the Norwegian sea

Cecilie Hansen, Isaac Kaplan, Hem Nailini Morzaria-Luna, Raphael Girardin, Kristin Marshall

Models and methods:

The model used in all simulations is the NoBa atlantis model, which includes 57 key species and functional groups in the Nordic and Barents Sea. The model is forced by a Regional ocean modelling system (ROMS) model, covering the area with a resolution of 20 km. The NoBa model domain is divided into 60 polygons, defined to be as homogeneous as possible.

Currently, nine simulations are performed. These are explained in Table A5.1. The only parameters changed between the different simulations were those concerning harvest and management. All biological parameters were kept constant, as was the physical forcing. Our next step is to evaluate the uncertainty connected to the biomass of zooplankton, by adding 15 additional simulations for each scenario, varying the zooplankton production. It is therefore very important to remember that the results only reflect one simulation per harvest control rule change.

Simulation name	Parameter change	Comment
Control1	None	Fisheries on mackerel at MSY level
Control2	None	Fisheries on mackerel and on herring at MSY level
Tier1	Hockey stick HCR for mackerel	Simple hockey stick implemented for mackerel
T7_1_0	Reduce harvest on mackerel when zooplankton biomass drops below threshold1	Ecosystem HCR on mackerel
T7_1_1	Reduce harvest on mackerel when zooplankton biomass drops below threshold2	Ecosystem HCR on mackerel
T7_1_3	Reduce harvest on mackerel when herring biomass drops below median	Ecosystem HCR on mackerel
T7_1_4	Increase harvest on mackerel when herring biomass drops below median	Ecosystem HCR on mackerel
T7_1_5	Increase harvest on mackerel when zooplankton drops below threshold1	Ecosystem HCR on mackerel
T7_1_6	Increase harvest on mackerel; when zooplankton drops below threshold2	Ecosystem HCR on mackerel

Table A5.1. Simulation set up for NoBa.

All simulations were run for a period representing the years 2004–2068. The physical forcing used is the NorESM downscaled simulations (ROMS), and LA04 (ROMS, different model grid) for the first two years. Forcing (temperature, salinity and currents) is needed on a daily basis in the NoBa model.

There are no other connections between mackerel, blue whiting and herring than the competition for food. The feeding-link between mackerel and herring is not added, this is possible by allowing a small fraction of the youngest age class of herring to be available for predation by adult mackerel. Atlantis does not include the larval stage; hence this is the only way to include the link. The importance of this link in the model system is something that should be evaluated.

T7_1_3 and T7_1_4 include fisheries at MSY level for both mackerel and herring, whereas in all other simulations only mackerel was harvested at MSY levels. The reasoning for switching between these two was the use of the ecosystem harvest control rules including herring in the two mentioned simulations. Other commercial components included in the simulations (e.g. Northeast arctic cod, capelin, golden, and beaked redfish, Greenland halibut, saithe, haddock, snow crab, and prawns) are run with historical fisheries for the period 2004–2016, thereafter at current level fisheries. The only exception from this is the capelin, where a representative fishing pressure is used, as the F from 2016 was 0.

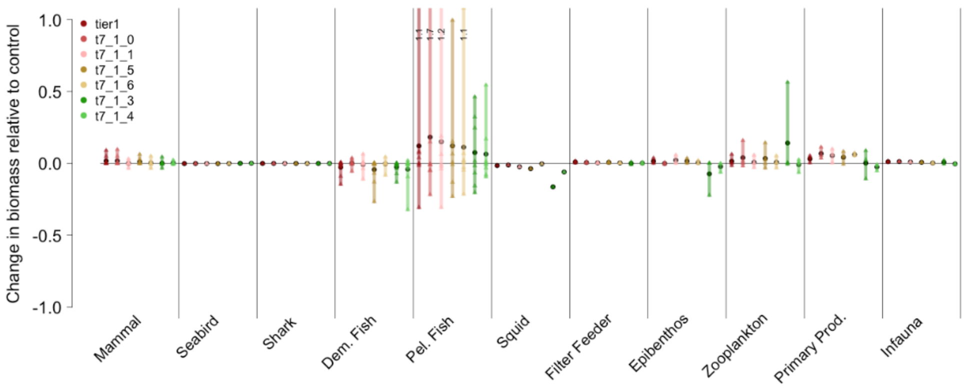

Figure A5.1. Response at guild level for the period 2017–2068. The dark colored dots are the average response in the guild for each simulation, whereas the slightly lighter colored triangles represent each of the species/functional groups included in the guild. Where there is only a number, it means that the biomass response in one (or more) of the groups are above 1, and the number is given in each

No (or very small) responses to the changes in management strategies can be seen for the seabirds, sharks, filter-feeders, and infauna. We see some response in the demersal fish, mainly negative, which is also the case for the epibenthos. There are low, positive effects from almost all runs in the primary production guild, likewise in the zooplankton guild. The solely positive responses seen in the first five simulations for pelagic fish is explained by the base case scenario that these are compared to. We compare all the first five simulations to a simulation where mackerel was fished at MSY without any harvest control rule. This gave by far the lowest biomasses for mackerel, hence the strong positive response seen in the other simulations. A few of the strategies gives a response in demersal fish, whereas the strongest response is seen in the pelagic fish, and also the zooplankton component. The simulation where the harvest of mackerel is decreased when the biomass of herring drops below a certain threshold stands out with its ecosystem response at the lower trophic levels (epibenthos, zooplankton and primary production), whereas the simulation where the harvest on mackerel increases when the herring drops below the threshold causes the strongest negative responses at the demersal fish level. The responses at demersal fish level was explained by indirect trophic interactions. It has to be noted that the strong positive response seen at the zooplankton level was caused by a couple of strong blooms within the small zooplankton functional group, hence not within the mesozooplankton group where the response was expected.

NoBa Atlantis cannot represent the reality year by year, as this is not the objective of such complex models, but does capture the trends in the biomasses fairly well for hindcast periods. This is the reason for showing the *differences* between the simulations, as we have no intention of using these model outputs for prediction.

The way the fisheries are implemented is important for the biomass development in the model. Implementing HCRs for all commercial components, including those that do not follow these currently could be an alternative method, but would also include discrepancies from the 'real' world.

We see that testing HCR's in a full end-to-end ecosystem model gives us more information about unexpected indirect effects, as the same time as we acknowledge the necessity of adding more simulations to these scenarios. Only this way we will be able to quantify some of the uncertainty connected to these.

The results are from Kaplan and Hansen *et.al.* (in prep), "Testing harvest control rules within end-to-end ecosystem models: a stepping stone toward management strategy evaluation."

Annex 6: Atlantic bluefin tuna in Norwegian Sea

Comeback kid – Atlantic bluefin tuna feeding in the Norwegian Sea and along the Norwegian coast

Bluefin tuna have probably been present in Norway for thousands of years (Tangen, 1999). Norway was one of the largest and dominating fishing nations targeting Atlantic bluefin tuna in the Northeast Atlantic Ocean during the 1950s and 1960s, with purse-seine catches reaching 15 000 metric tonnes inside the Norwegian Exclusive Economic Zone (EEZ) (Hamre and Thiews, 1964; Nøttestad and Graham, 2004; 2005; ICCAT 2016). The bluefin tuna arrived historically along the Norwegian coast, at the northern borders within their natural distribution area and migration routes, in several runs with the timing and migration pattern depending on the size and age composition of the schools (Hamre and Thiews, 1964; Tangen, 1999). The first fish appeared in early July, starting with the arrival of the largest fish, and extended through to October (Nøttestad and Graham, 2004). There were two important periods with respect to migrations affecting the Norwegian fishery, from 1950 to 1962 and from 1963 to 1985 (Hamre and Thiews, 1964; Nøttestad and Graham, 2004; 2005).

The first recorded catch of bluefin tuna taken by purse-seine in Norway was done in 1926 (Tangen, 1999). The first major period started in the 1940s, which was categorized by a range of age groups being present in Norwegian waters. In the early period, several year classes, probably from the early 1940s, provided high catches along the whole coast of Norway up to at least 71°N. The older fish, up to 200 kg, arrived in early July and migrated to the northerly part of the Norwegian coast. After feeding there for 3–4 weeks the fish migrated quickly southwards into the bank area of the North Sea (Hamre and Thiews, 1964). The youngest individuals, up to 70 kg, migrated to the southeastern part of Norway, while most medium sized tuna remained in southwestern Norway from July to October (Hamre and Thiews, 1964; Tangen, 1999). During this period, the fishery gradually decreased in range, and by the early 1960s very few fish were caught north of 62°N, presumably due to the demise of the year classes from the early 1940s. From about 1956 onwards, the fishery relied mostly on the strong year classes from 1950 and 1952 (Cort and Nøttestad, 2007).

From 1963 onwards, the fishery in Norway consisted mainly of the 1950 and 1952-year classes, while the largest tuna from the 1940s was not present in sufficient numbers for a viable fishery of the northern areas off the Norwegian coast, and the majorities of catches were taken south of 62°N (Cort and Nøttestad, 2007).

Norway sustained the largest fishery for bluefin tuna in the Atlantic Ocean between 1950 and 1964 with catches reaching 15 000 metric tonnes. The vessels engaged in the fishery in Norway, counted 450 fishing vessels during the most active years in the 1950s. These fishing vessels were normally engaged in the herring and mackerel fisheries outside the bluefin tuna season stretching from July to October. They were typically 15–22 m in length, using purse-seine nets ranging from 400 to 1000 m in length and between 60 to 100 m in depth. Individual and groups of vessels searched for tuna along the coast up to fifty nautical miles offshore, using seabird activity and surface behaviour of individual tuna as indicators of bluefin tuna shoals. The Norwegian fishery ceased in the early 1980s as the abundance of bluefin tuna was severely reduced. Bluefin tuna was occasionally observed in Norwegian waters during the 1980s and 1990s, but not in quantities that could sustain a commercial fishery.

Atlantic bluefin tuna (*Thynnus thunnus*) has now returned to Norwegian waters, and are once again re-establishing their traditional annual feeding migration pattern.

Schools of bluefin tuna are distributed into the Norwegian Sea and along the Norwegian coast as documented in previous decades. The recent observations of bluefin tuna in Norwegian waters started to appear around 2013. In 2014 more observations were made, including a bycatch of bluefin tuna taken by a purse-seiner fishing on western horse mackerel in the southern part of the Norwegian Sea in August 2014.

There have been numerous observations concerning bluefin tuna in 2016 (Figure A6.1) and 2017 (Figure A6.2), from Lindesnes in the south to Tromsø in the north and from June to November. Bluefin tuna have been observed feeding as far north as 68°30′N in late February 2017. This is the first time bluefin tuna have ever been observed and reported in Norwegian waters during winter, probably due to highly favorable feeding conditions. Totally 191 individuals and around 44 000 kg were caught from targeted bluefin tuna fishing in 2016. Totally 235 individuals and around 53 000 kg were caught from targeted bluefin tuna fishing in 2017. A positive sign of the stock rebuilding is now visible in northern waters due to numerous sightings where sightings of small to large aggregations/schools have been recorded in Norwegian waters during the last few years.

The major driving force for the reappearance of bluefin tuna in Norwegian waters is probably increased need for prey, due to increased stock size over the last decade. Bluefin tuna are thus migrating further and further northeast into the very productive Norwegian Sea ecosystems, probably representing some of the most important feeding grounds for decades concerning Atlantic bluefin tuna. due to the high biomasses in the range of 10–15 million tonnes of preferred prey species for bluefin tuna, including Norwegian spring-spawning herring (*Clupea harengus*), mackerel (*Scomber scombrus*) and blue whiting (*Micromesistius poutassou*) (Nøttestad *et al.*, 2016; ICES 2016a, b). A bluefin tuna could easily gain 40–50 kg weight from July to October in Norwegian waters when feeding abundantly on fat and nutrient rich pelagic planktivorous prey species such as herring, mackerel and sprat. Based on stomach samples from bluefin tuna caught in Norwegian waters in 2016 and 2017 they had predominantly preyed on 0-group mackerel. Individuals had also to a lesser extent eaten larger mackerel, herring, blue whiting, and gadoid species.

A 300 kg bluefin tuna coming from the Mediterranean Sea in spring, could eat so much that the same individual could weigh up to 350 kg when the feeding period ended in October. Due to the high metabolism of bluefin tuna a large individual may possibly consume in the range of 1500 kg prey during one feeding season. Furthermore, large amount of bluefin tuna that may potentially feed in increasing numbers within Norwegian waters in the years to come, may account for in the range of 100 000 tonnes of valuable pelagic prey species taken out by bluefin tuna each year in Norwegian waters (Trenkel *et al.*, 2014). Since the Norwegian Sea and surrounding waters are among the most productive marine ecosystems sustaining some of the most abundant pelagic fish species in the Atlantic Ocean (Huse *et al.*, 2012; Nøttestad *et al.*, 2016; ICES 2016), it should not be surprising that Norway used to be one of the largest fishing nations on bluefin tuna within the Atlantic Ocean. An increasing bluefin tuna stock will exploit feeding opportunities further and further to the north due to increased intraspecific and interspecific competition for available prey.

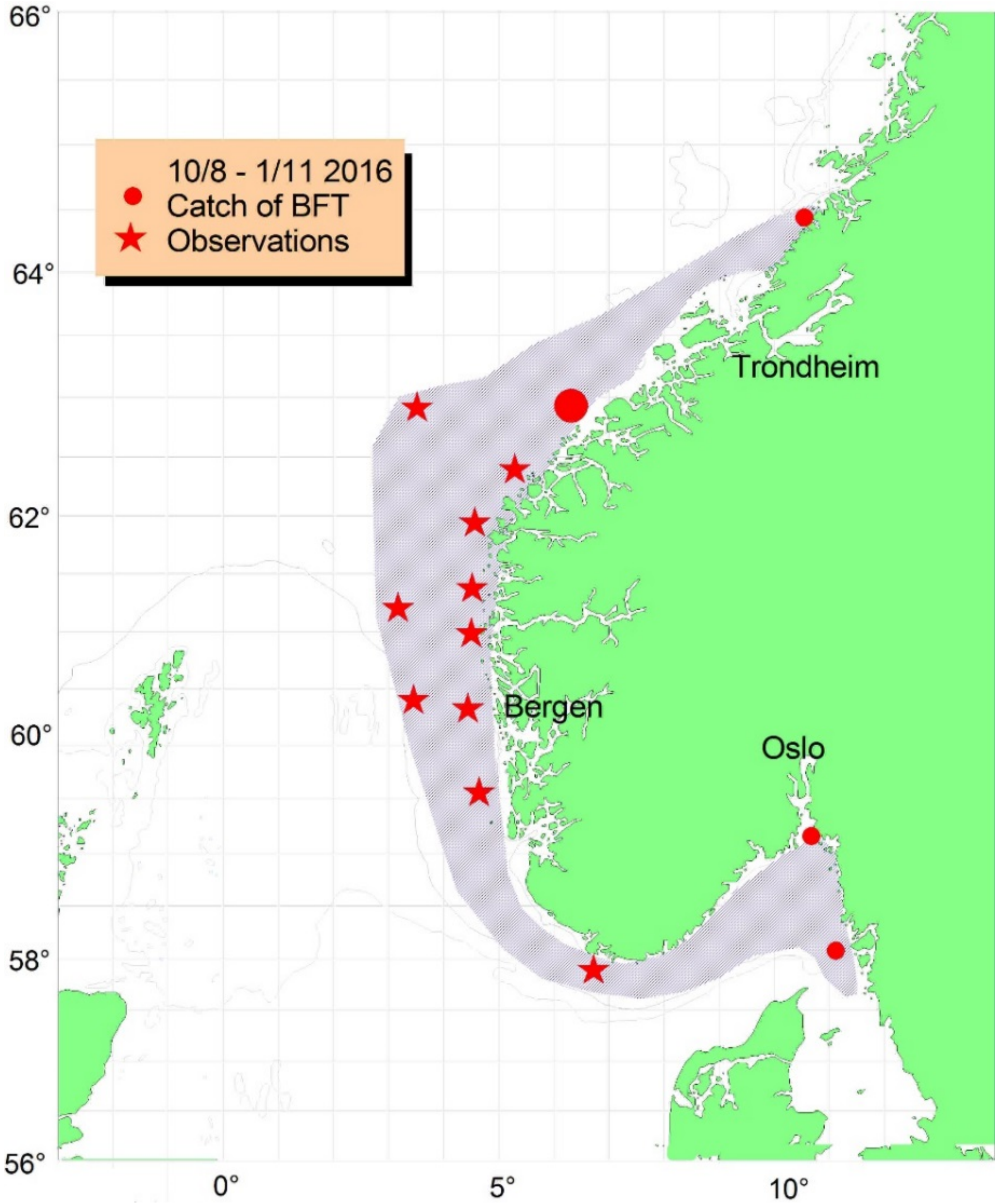

Figure A6.1. Geographical positions on catches and observations of bluefin tuna from August to November 2016.

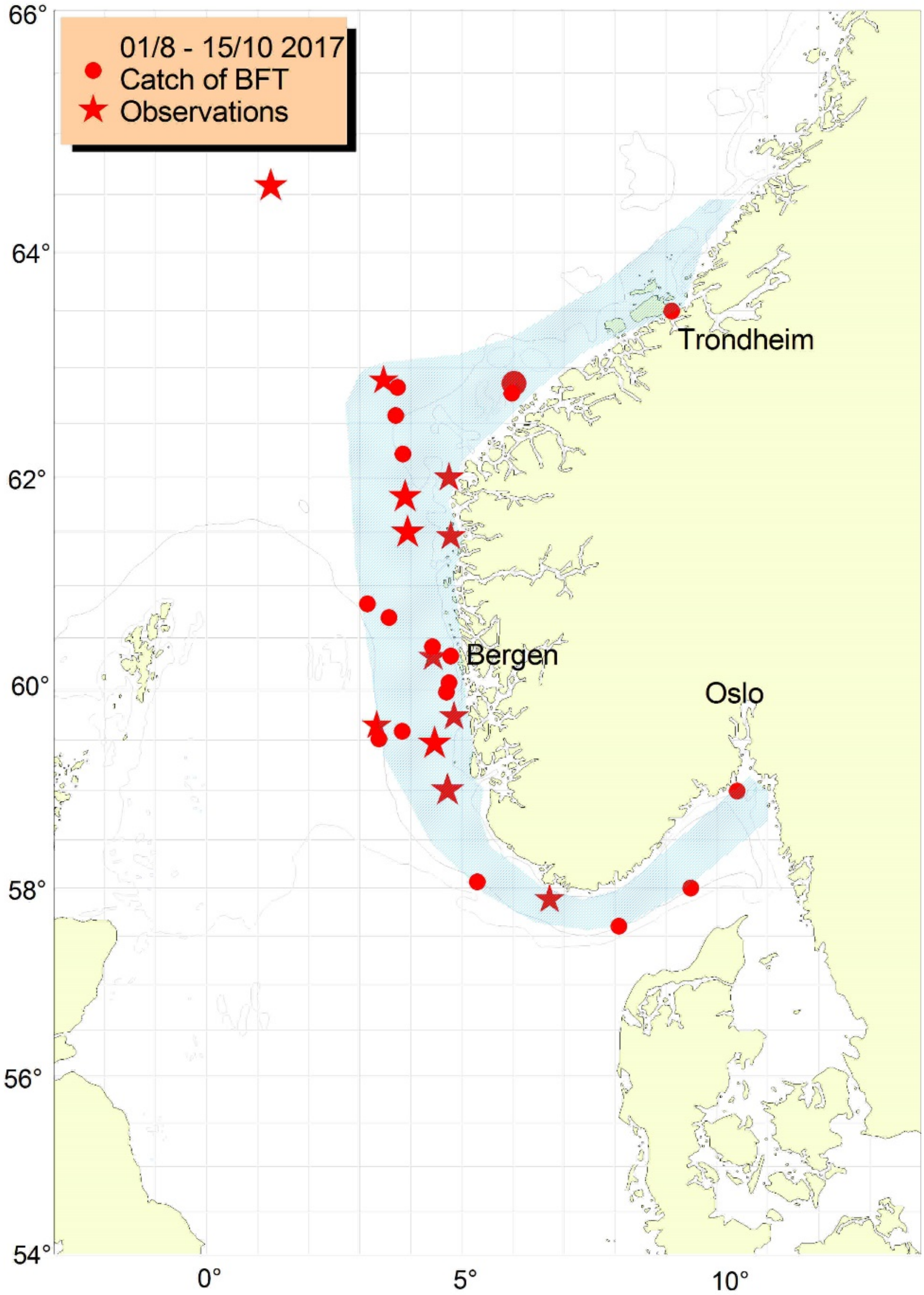

Figure A6.2. Geographical positions on catches and observations of bluefin tuna from August to October 2017.

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Annex 7: Draft program for a task on the dynamics of the Norwegian Sea pelagic ecosystem

Dynamics of the Norwegian Sea Pelagic Ecosystem

Meeting organized by WGINOR and the EcoNorSe project

Bergen 16-19 October 2018

Start with lunch on the 16, end at 14:00 on the 19

Chaired by Per Arneberg (IMR) and Eydna í Homrum (FAMRI)

The aim of this task is to progress on our understanding of the dynamics of the pelagic ecosystem in the Norwegian Sea. The task will result in a paper summarizing our current understanding as it emerges from the meeting, and point to important areas for future research.

The task will be run by a combination of plenary presentations, discussions and group sessions where the primary focus will be to work with the paper. The meeting will be organized around three themes:

1. Aspects of the physical environment that are important for dynamics of the ecosystem;
2. Direct effects of the physical environment on ecology;
3. Species interactions and synthesis for overall understanding of the ecosystem dynamics.

Below, each theme is described in more detail together with an outline of issues to be presented and discussed.

1. Aspects of the physical environment important to dynamics of the ecosystem

Important physical processes known, or suspected to, have important direct effects on key biological processes will be described. We will also investigate the potential of using environmental or ecological indices as indicators of the state of the ecosystem. This is tightly coupled with theme 2 that deals with the nature of such effects, which are related to for example variations in primary productivity, zooplankton dynamics and pelagic fish recruitment.

2. Direct effects of the physical environment on ecology

The primary focus of this theme will be on important direct effects of the physical environment on key biological processes, including effects on primary productivity, zooplankton dynamics and recruitment in the herring, mackerel, and blue whiting stocks. Indirect effects of the physical environment (for example effects on fish stocks caused by changes in zooplankton dynamics that have their primary roots in variation in the physical environment) will not be addressed in this theme, but taken up under theme 3.

3. Species interactions and synthesis for overall understanding of the ecosystem dynamics

The aim is to synthesize knowledge and information about processes and components to improve our overall understanding of the dynamics of the ecosystem. This will be done by focusing on foodweb structure and methods for integrated analyses. With this as a background, the following processes and groups will be addressed:

a) Intra- and interspecific processes in the pelagic fish stocks;
b) Effect of changes in zooplankton productivity on fish stocks and vice versa;
c) Seabirds, with focus on how they are affected by what happens in the ecosystem;
d) Marine mammals, with focus on how they can affect the dynamics of the system;
e) The role of groups we have limited knowledge of, such as:
    i) Squids
    ii) Krill
    iii) Amphipods

Annex 8: Proposition for a task on developing SEM for herring recruitment in the Norwegian Sea.

Norwegian Spring Spawning Herring (NSSH) is one of WGINOR key pelagic species and it plays a key role in the Norwegian Sea ecosystem and for the pelagic fisheries operating in the region. Recruitment of NSSH is known to vary widely at interannual and interdecadal scales and these variations have been documented for nearly a century. There is a wide body of knowledge, hypotheses and data on the control of recruitment of NSSH. Hypothesized mechanisms involve abiotic controls (e.g. temperature) as well as biotic interactions (e.g. predation or competition). The purpose of this task is to contribute towards a synthesis of the various hypotheses (which can be competing or complementary) and to perform an evaluation of the possible causal mechanisms at play. The approach envisaged is structured in three steps:

- Participatory construction of causal - graphical - models of NSSH recruitment. An illustration of such causal model for blue whiting in the Northeast Atlantic is shown in Figure A8.1.
- Building of structural equation models (SEMs) that correspond to the causal models proposed.
- Evaluation of the models against available abiotic and biotic data.

This task will require participation from experts in physical oceanography, herring biology and ecology, functioning of the Norwegian Sea ecosystem and structural equation modelling. Anticipated outcomes include a synthesis of hypotheses for the control of NHSS recruitment, a series of causal models of recruitment, an evaluation of these models and ultimately a peer reviewed publication presenting those results.

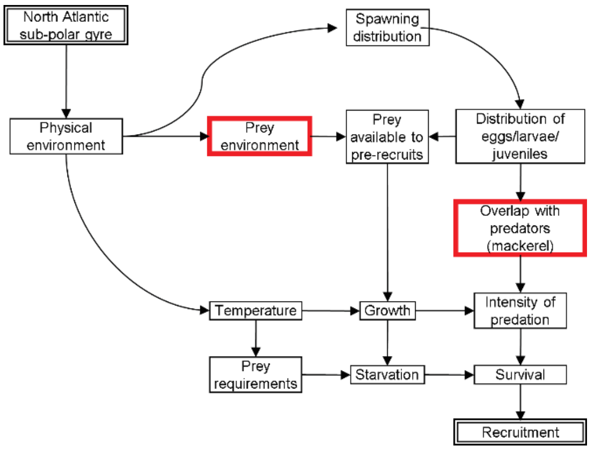

Figure A8.1. Summary of the proposed mechanisms potentially explaining recruitment of blue whiting. Arrows indicate causal linkages between phenomena and should be read as 'influences'. Reproduced from Payne *et al.* (2012)

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